Stochastic Cooling, Developments and Plans

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Acknowledgements: J. Wei, Beam Components Group, and the RF Group

Problems

Solutions

Plans for FY06

Two Main Problems

1. High voltage (x bandwidth) for the kickers
   - Longitudinal cooling
   - 100 GeV beam
   - 4 GHz bandwidth
2. The COHERENT components versus Schottky signals
   - Simply put: this KILLED S.C. at SPS and Tevatron
   - Is there some strange beam physics effect that is not completely understood?
   - We have q=79 on our side
   - Technology has progressed in the GHz range

Kickers

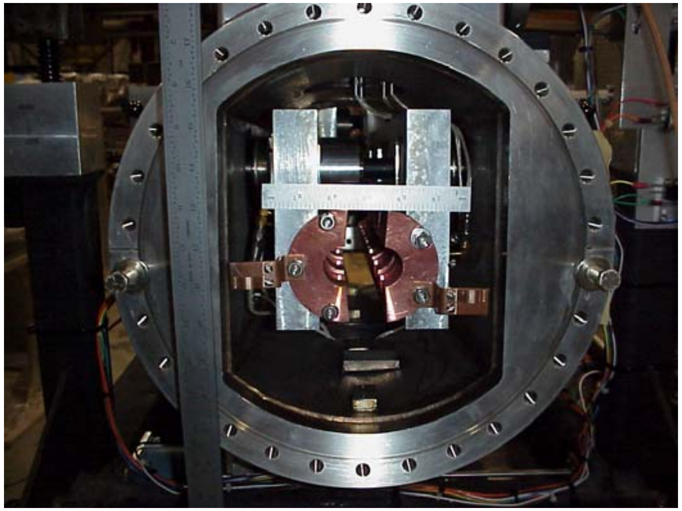
- The kicker must correct 1/5 of the measured fluctuations per kick
- Fluctuations are proportional to sqrt(N_{sample})
- 8 GHz system gives 125 ps sample
- 3 kV with a 50 Ohm kicker would take 90 kW

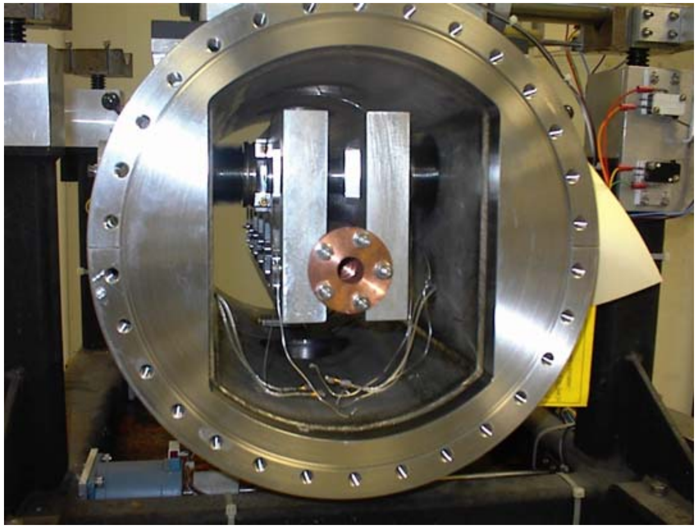
$$\delta E_{kick} = g_{opt} \frac{\sigma_E}{\sqrt{N_{sample}}} = g_{opt} \frac{\gamma A m_u \frac{\Delta p}{p}}{\sqrt{T_{sample} \frac{10^9}{5ns}}}$$

$$= \frac{1}{5} \frac{100 \;\; 197 \; 1 GeV (0.3 x 10^{-3})}{\sqrt{125 ps \frac{10^9}{5ns}}} = \mathbf{250\ keV}$$

$$V_{kicker} = \frac{\delta E_{kick}}{79} = \mathbf{3 kV}$$

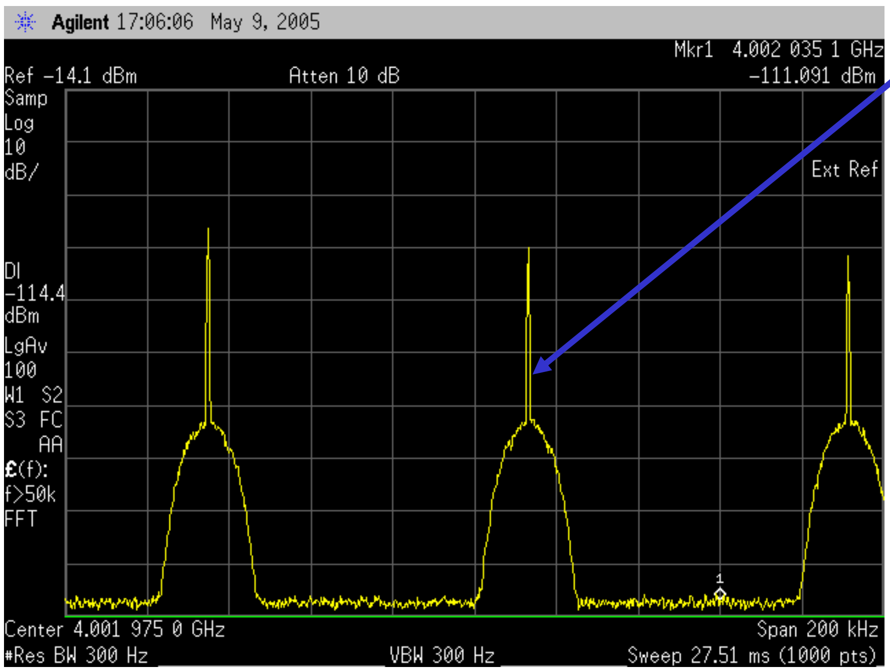
Kickers





- The solution is to use high Q cavities
- Exploit the fact that the beam is bunched
- We can fill the cavities for 80ns between bunches (power leveling)
- Q ~ 1000, R = 10^4 ohms, Power= 20 Watts
- The low level gets a bit more tricky
- The aperture of the cavities is 20 mm
- Beam measurements (BTF and signal suppression) showed we have enough voltage

Coherent Line Problem



Spectrum of protons at 4 GHz

- The coherent component has nothing to do with the fluctuations (emittance/temperature) of the beam
- It is not part of the beam distribution that can be cooled
- But it can defeat the cooling electronics by saturating the electronics
  - Pickup amplifiers
  - Signal processing filters
  - Kicker power

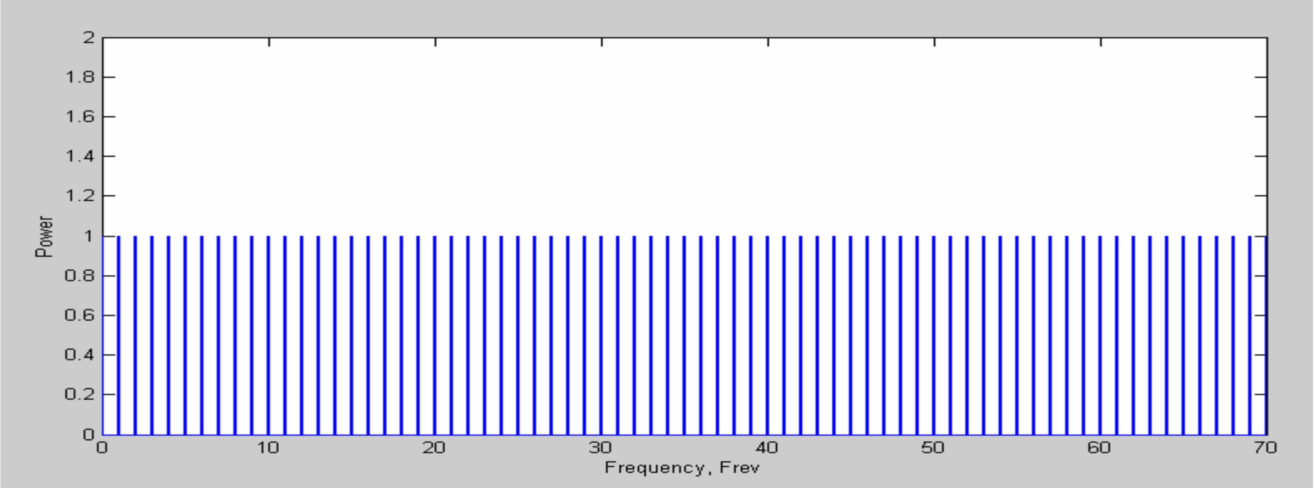
Coherent Line Problem

- We have spent more time and effort on this problem than any other aspect of the system
  1. Is there something in the beam physics that is not understood?
  2. Is there something fundamentally different between protons and ions?
  3. Can we cope with these coherent components in the electronics?

What is Meant by Coherent Component?

If you have one particle in the ring, Nd (Z=60)

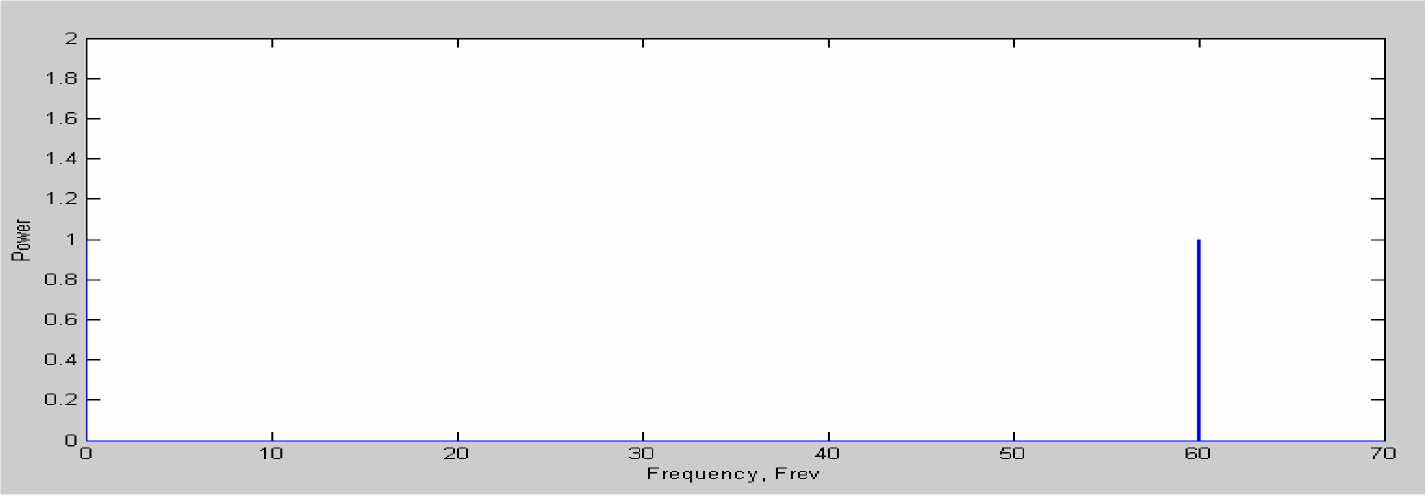
$$I(t) = \frac{60e}{T_{rev}} \sum_{n=-\infty}^{n=+\infty} \delta(t - nT_{rev}) = \frac{60e}{T_{rev}} \sum_{k=-\infty}^{k=+\infty} e^{ik\omega_0 t}, \quad \omega_0 = \frac{2\pi}{T_{rev}}$$



Coherent Line

- If we have 60 protons in the ring, evenly spaced, every 6 buckets

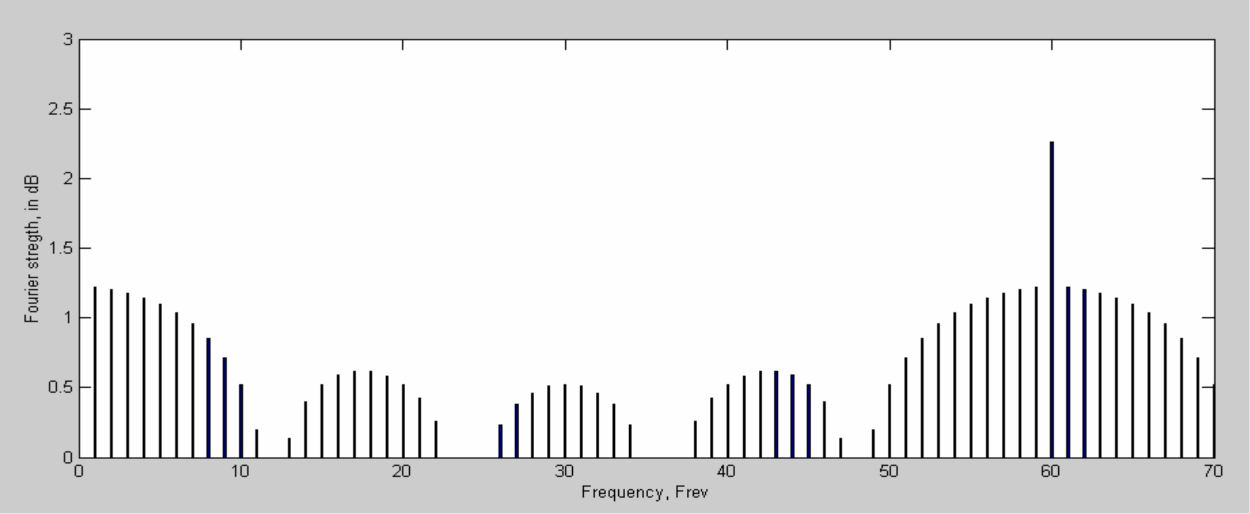
$$I(t) = \frac{60e}{T_{rev}} \sum_{n=-\infty}^{n=+\infty} \delta(t - nT_{rev} / 60) = \frac{60e}{T_{rev}} \sum_{k=-\infty}^{k=+\infty} e^{ik60\omega_0 t}, \quad \omega_0 = \frac{2\pi}{T_{rev}}$$



What has happened is that the (exactly) evenly spaced bunches have (exactly) cancelled all Fourier harmonics up h=60.

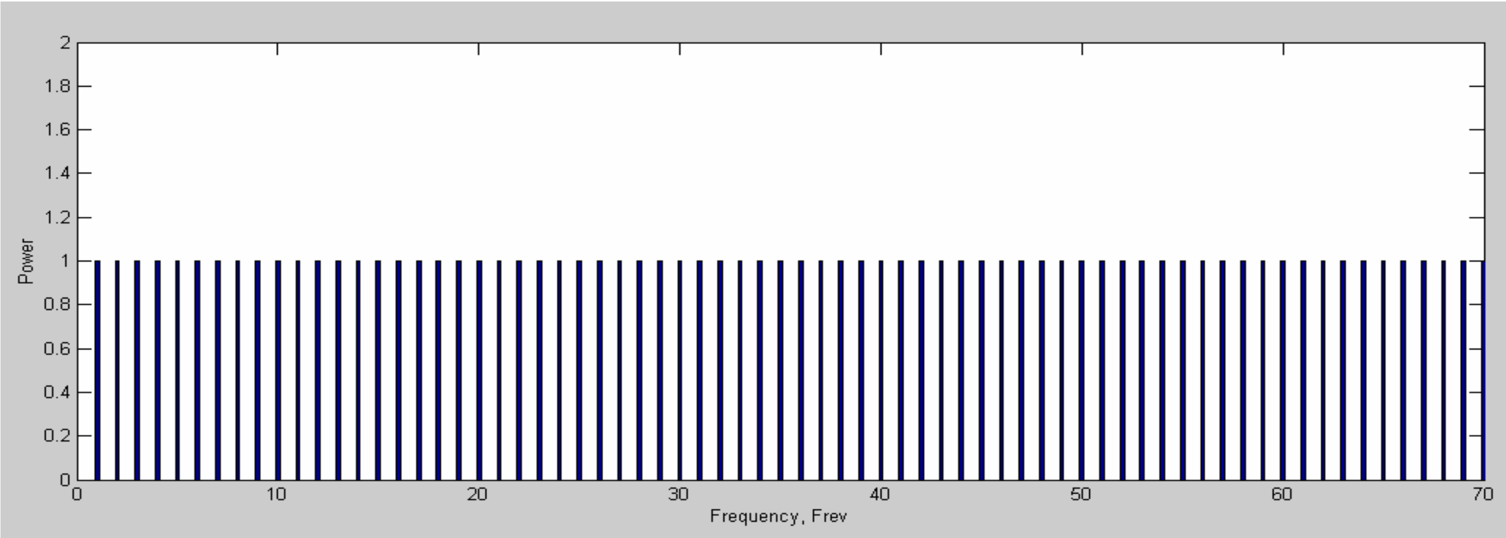
If we have 55 bunches with an abort gap the cancellation is not complete for all the F_{rev} lines

$$I(t) = \sum_{n=-\infty}^{n=\infty} \alpha_n e^{in\omega_0 t}, \quad \text{where } \alpha_n = \frac{1}{T_{rev}} \int I(t) e^{-in\omega_0 t} dt$$



All Frev lines appear, and the shape of the spectrum depends on the bunch pattern.

Now if the 60 particles are de-bunched, the pattern is completely random around the ring. The spectrum looks the same as the one-particle spectrum, except the power per line is much less than for one particle of charge 60, Nd ion.



$$P_{line}(\omega) = \sum_{n=1}^{60} I^2(\omega)R = 60I^2R$$ for 60 random ions of charge 1

$$P_{line}(\omega) = (60I(\omega))^2 R$$ for one ion of charge 60

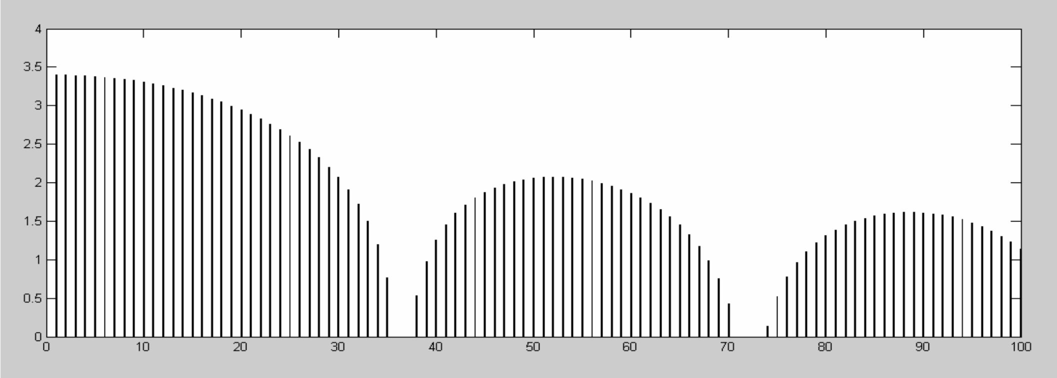
We say that the randomly distributed particles are incoherent, and the 60 charges locked together are coherent. 60 times more power.

That's why you can see a Schottky spectrum from a de-bunched beam. Each particle gives its own spectrum and they add up.

But what if the beam IS bunched? Then the particles are not random, they are coherent, so we must multiply by the number of particles and then square. If $N=10^9$, this is huge. The Schottky signal, incoherent, gets swamped by the coherent signal.

But the coherence is limited in frequency.

$$\alpha(f) = \frac{\tau_b}{T_{rev}} \sum_{n=-\infty}^{n=\infty} \left[\frac{\sin(\pi n \frac{\tau_b}{T_{rev}})}{\pi n \frac{\tau_b}{T_{rev}}} \right] \delta(f - \frac{n}{T_{rev}})$$



Spectrum of bunch, length τ_b

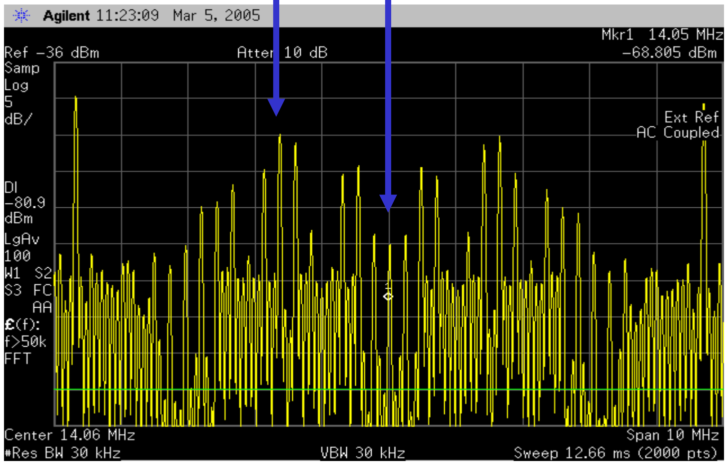
The bunch cannot be coherent at a frequency so high that it looks like de-bunched beam. That is, when the wavelength is much shorter than any features of bunch shape. $P=I^2R$ is over simplified

Our coherent lines at 8 GHz are much stronger that what one would expect of a 5 ns Gaussian bunch. Why?

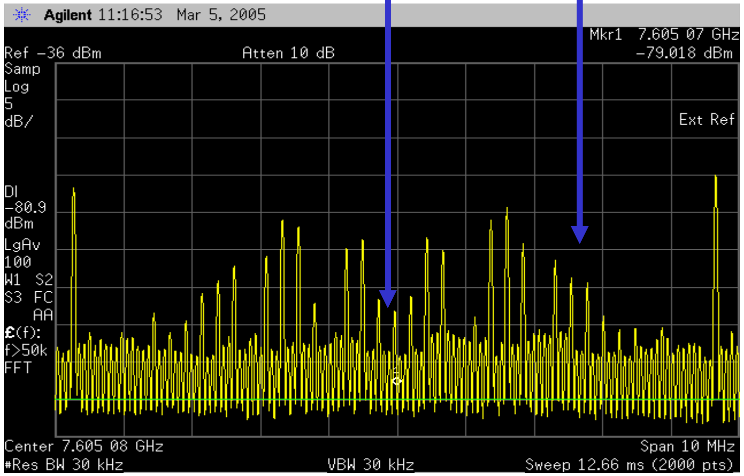
- "hot spots" in the bunches?
- Solitons?
- Occult?
- How will this affect cooling? >overcome technical obstacles

The key to the answer is in the way the frequency spectrum reflects the bunch pattern.

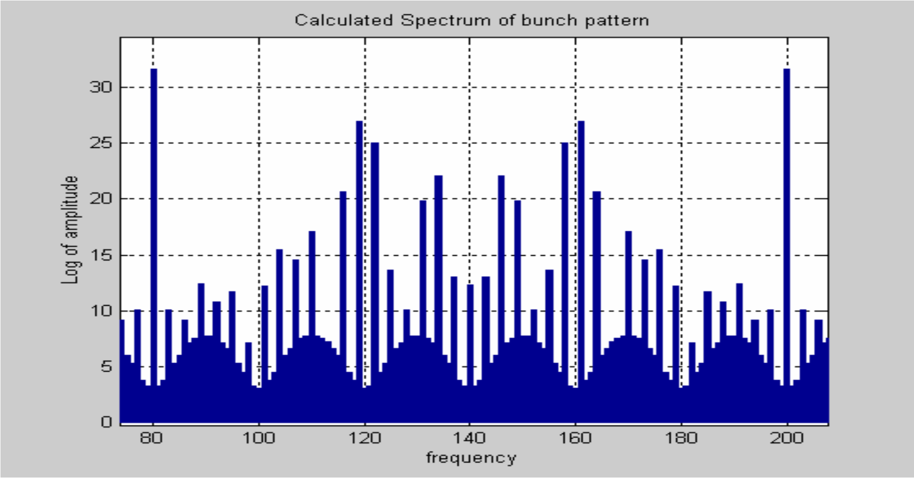
All bunches have the same shape and are locked exactly to the revolution frequency



Spectrum at low frequency from Wall Current Monitor



Spectrum at 7.6 GHz from stochastic cooling pickup

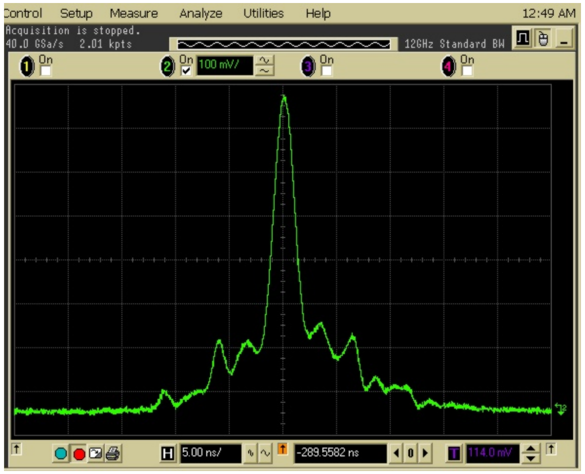


We looked at the pickup signal with the superscope (40 Gs/s, thanks Agilent)

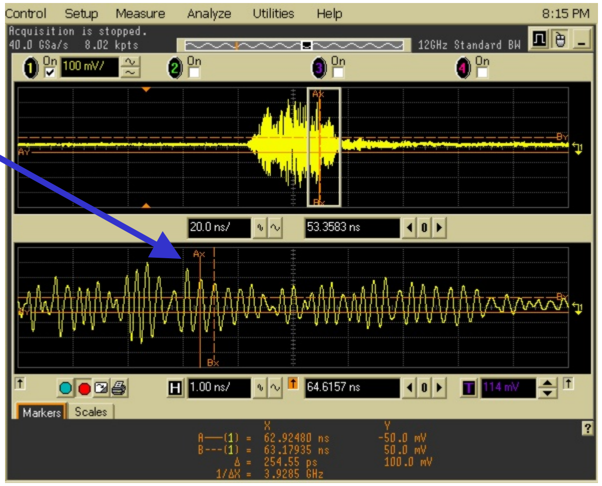
- Indeed the bunch does have structure at 4-8 GHz

- The pickup structure has a resonance at 4 GHz

- The features of the signal are stationary, not fluctuating

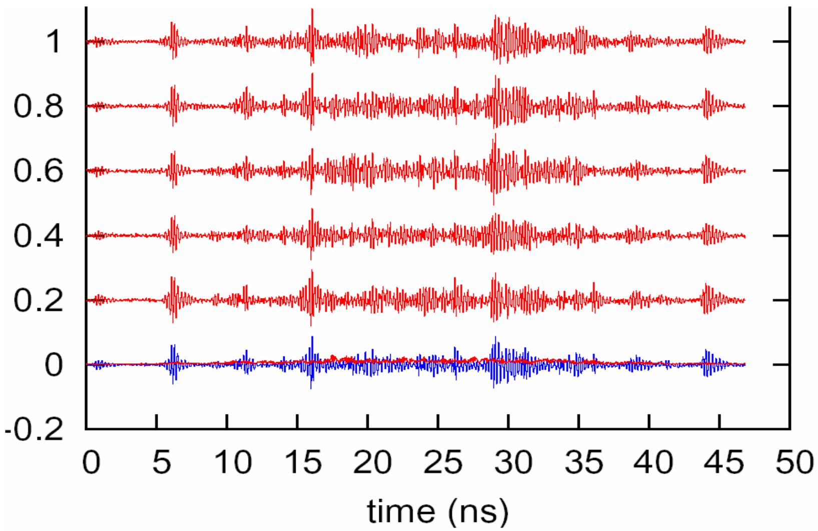


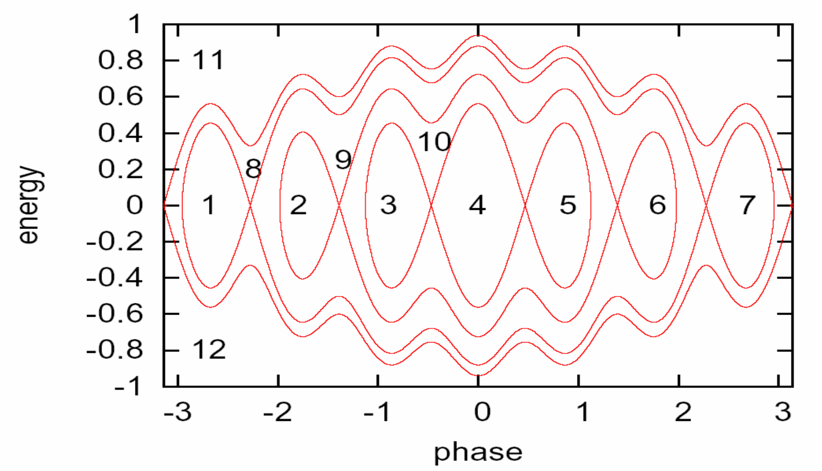
Bunch profile from wall current monitor, 0-500 MHz



Signal from stochastic cooling pickup, 4-8 GHz

The plausible explanation for this bunch shape is the 28/197 MHz double rf system and rebucketing plus IBS





Red is 5 different bunches lined up. Blue is the average of the 5 bunches

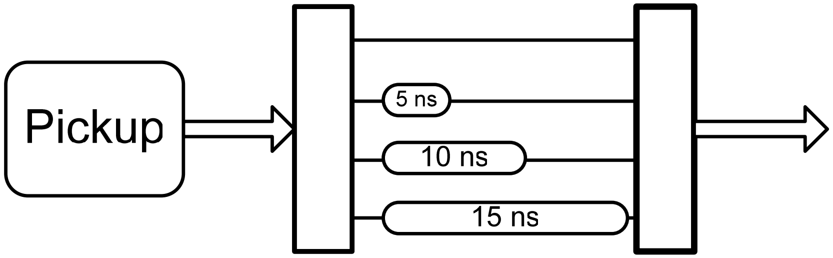
Complicated separatrix of double rf system. There are several fixed points where particles pile up make cusps in the line density.

The conclusion is that the coherent component is there because the bunch shape has significant strength at 8 GHz.

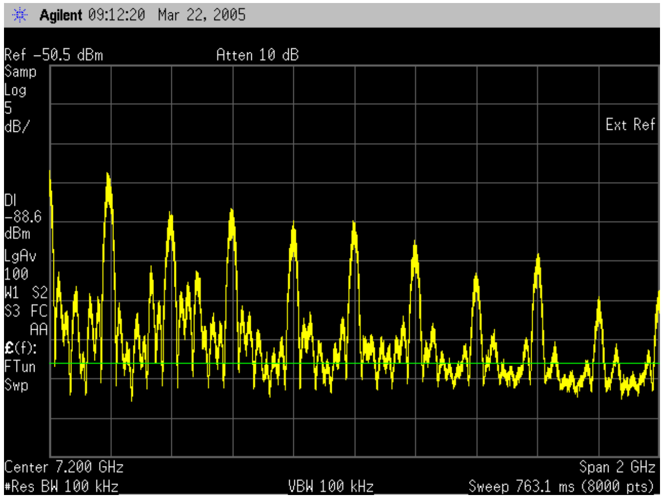
- It is not some crazy beam dynamics effect that we should be afraid of
- The coherent part is strong and could saturate the electronics
- We have to build a system that can cope with these coherent signal

Key results from this year’s run

- Filtering the pickup signal
  - A traversal filter to reduce the dynamic range
  - A notch filter to kill the pickup structure resonance at 4 GHz

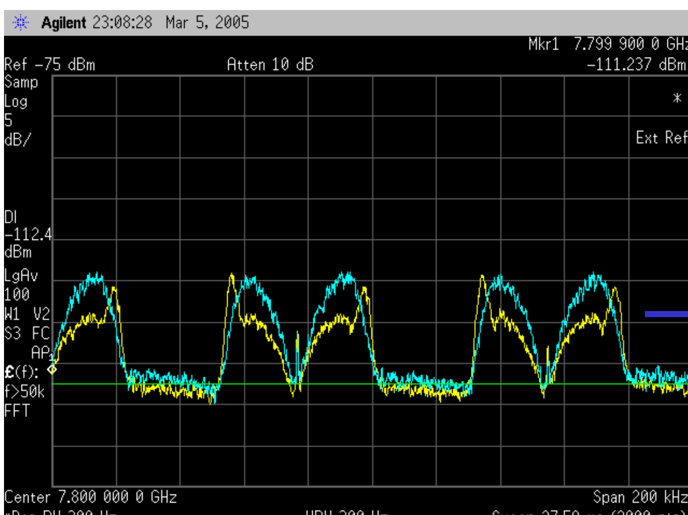


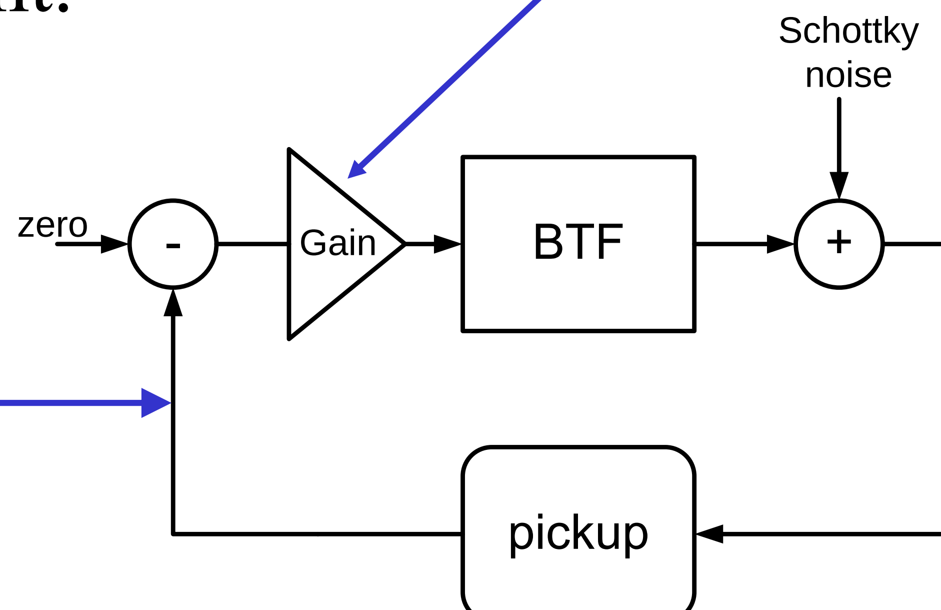
Peak voltage reduced by ¼. Passes frequencies every 200 MHz (=1/bunch length)



Key results from this year's run

- Signal suppression shows that the cooling feedback loop is closed and the gain (kicker voltage) is sufficient.





Plan for FY06

- Build an "operational" cooling system for yellow
  - Build and Install new 16 cavities (CW power capable)
  - Move pickup from Q4_11 to Q4_12 to reduce delay (fill time for cavities)
  - Build 16 low-level control boxes
  - Stabilize the delay drifts by automatic compensation from the Network Analyzer
- The cost is ~ 240 k$ to complete yellow
  - Must spend 100 k$ in FY05
  - Defer 150 k$ to FY06